무선인지기반 위성시스템을 위한 주파수 검출방법

A Spectral Correlation Method for Cognitive Radio based Satellite system.

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요 약

무선인지기술은 환경에 능동적으로 적응하여 스펙트럼 이용을 효율적으로 할 수 있도록 하는 기술이다. 무선인지 기술의 가장 중요한 첫 단계는 센싱 부분으로서 본 논문에서는 주파수 상관관계를 이용한 방법을 제안하였다. 통신신호의 주기적인 특성을 기반으로 잡음과 간섭의 효과를 최소화하기 위해 주파수 상관함수를 사용하였다. 이미 알려진 에너지 측정 방법의 동작특성을 보이고 시뮬레이션을 통하여 제안된 측정 방법과 기존의 방법을 비교하여 무선인지환경을 이용한 스펙트럼 센싱의 효율성을 보인다.

ABSTRACT

Cognitive radio, which is designed to dynamically adapt its transmission to its environments is believed to be one of the fundamental techniques for the future spectrum utilization. As the first step of cognitive radio, spectrum sensing is treated as the most important technique. In this paper, we propose a spectral correlation based detection method for spectrum sensing. Based on the cyclostationarity of communication signals, spectral correlation function is used to minimize the effect of random noise and interference. The ROC performance of conventional energy detection is shown. Simulation results show that the proposed detection method outperforms the energy detection and more suitable for spectrum sensing in cognitive radios.

Key Words : cognitive radio; spectrum sensing; cyclostationary; spectral correlation; satellite communication.

Ⅰ. Introduction

The demands for broadband services by satellite communications are growing rapidly. Future satellite systems will provide many new services such as high-speed internet access and broadband multimedia services[1-3]. Because of the limited frequency spectrum for satellite communications, it is very important to improve the spectrum efficiency to enhance the system capacity. However, actually used spectrum efficiency is different depends on the time and location. The FCC(Federal Communications Commission's) frequency allocation chart indicates overlapping allocations over all of the frequency bands, which reinforces the scarcity mindset. The FCC's Spectrum Policy Task Force who reported[4]

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vast temporal and geographic variations in the usage of allocated spectrum with utilization ranging from 15% to 85%. Under this circumstances, spectrum deregulation is a necessary step in the future for increasing spectrum efficiency. Cognitive radio is proposed as a candidate solution to scavenge the idle spectrum[5]. The term Cognitive Radio is defined by Joseph Mitola Ⅲ within his dissertation.[6] It is an intelligent wireless communication system that is aware of its surrounding environment, and dynamically adapt its operating parameters in real-time to realize highly reliable communications whenever and wherever needed with efficient utilization of the radio spectrum. With the ability to learn from and adapt to both their surrounding environment and user needs, cognitive radio offers a great number of benefits in almost all markets of interest: military, government, public safety, commercial and satellite. In contrast to the other communication type, a satellite communication signal covers bigger region even than that of WRAN or TVs'. Because satellite locates at 35,000km above the Earth, only a thin signal from the satellite it could cover more than 10km of diameter on surface of the Earth. In other words, it can affects the other signals and make interference on them. However, other signal bands such as ISM(Industrial Scientific Medical) band have to be protected from satellite signals or avoid its effect. In some cases, other devices might use the satellite spectrum at that time they can use the cognitive radio technology. The speciality of the satellite signal is that we can detect the signal even in the low SNR case. Therefore we need another detection method which can detect the low SNR signal. Conventional detection method which includes energy detection models the signal of interests as a stationary random process. Mean while cyclostationary models for communications signals have been shown in recent years to offer many advantages over stationary models. One such advantage is the correlation between spectral components that many signals exhibits. The theory of spectral correlation in cyclostationary signals developed in and has been shown to provide a unifying conceptual and mathematical framework for signal detection based on cyclic feature exploitation.[7-8] In this paper, we proposed a spectral correlation based method which is based on the cyclostationary model of signals. In the second part, the detection problem is described. After that, the review of cyclostationary signal processing theory is included and the proposed peak detection method is described in details. In the fourth part, some simulation results and analysis are shown. At last, conclusions are drawn to finish the statement of this paper.

Ⅱ. System Model

1. Binary Hypothesis Detection

Spectrum sensing which relies on the detection techniques is a procedure to search the empty frequency bands for secondary users. As we have explained, there is no designated band only for secondary user transmissions; therefore, the detection procedure is essential for the success of interference avoidance.

The problem of spectrum sensing is indeed a simple binary hypothesis detection problem[9]. This two hypothesis test is modeled as:

(1)H_0: only noise in the received signals:

$$r(t)= n(t) \tag{1}$$

(2)H_1: noise plus message signals in the received signals:

$$r(t)= s(t)+ n(t) \tag{2}$$

here r(t), n(t) and s(t) are defined as the received signals, noise and transmitted message signals, respectively.

The general detection procedure composed of two parts. A measurement should be made based on the received signals at first, according to a certain criteria, the detection decision is made.

2. Cyclostationary

Generally, the signal of interest is modeled as a stationary random process. However, in most of the communication systems, the signal of interest can be treated as a cyclostationary random process instead. In this section, we introduce some basic knowledges of cyclostationary random process and define the spectral correlation function which will be used in our proposed method.

A process, for instance X(t), is said to be cyclostationary in the wide sense if its mean and autocorrelation are periodic with some period, say T [10]:

$$m_X(t+T) = m_X(t) \quad (3)$$

$$R_X\left(t+T+\frac{\tau}{2}, t+T-\frac{\tau}{2}\right) = R_X\left(t+\frac{\tau}{2}, t-\frac{\tau}{2}\right) \quad (4)$$

$Rx(t+\tau/2, t-\tau/2)$, which is a function of two independent variables, t and τ, is periodic in t with period T for each value of τ.

The SCF (spectral correlation function) which is also known as the cyclic spectral density function could be measured by the normalized correlation between two spectral components of x(t) at frequencies $(f+\alpha/2)$ and $(f-\alpha/2)$ over an interval of length Δt.

$$S^{\alpha_i}_{xT}(f)_{\Delta t} = \frac{1}{\Delta t}\int_{\Delta t/2}^{-\Delta t/2} \frac{1}{\sqrt{T}} X_T\left(t, f+\frac{\alpha}{2}\right) \cdot \frac{1}{\sqrt{T}} X_T^*\left(t, f-\frac{\alpha}{2}\right) dt \quad (5)$$

In (5) the spectral of x(t) over the time interval [t-T/2,t+T/2] is defined by:

$$X_T(t,v) = \int_{-T/2}^{+T/2} x(u) e^{-j2\pi v u} du \quad (6)$$

The ideal measurement of the SCF for the received signal x(t) is given by:

$$S_x^{\alpha_i}(f) = \lim_{T\to\infty} \mathrm{Lim}_{\Delta t\to\infty} S_{xT}^{\alpha_i}(f)_{\Delta t} \quad (7)$$

In order to general the SCF, the procedure in figure 1 can be used. The spectral correlation characteristic of the cyclostationary signals provides us a richer domain signal detection method. Different modulated signals have their unique cycle frequencies. The SCF of primary user signals are shown in figure 2. Their unique cycle frequencies are obviously. We can accomplish the detection task by searching the unique cyclic frequency of different modulated signals. Also, information such as the carrier frequency, chip rate could be calculated according to the unique cyclic

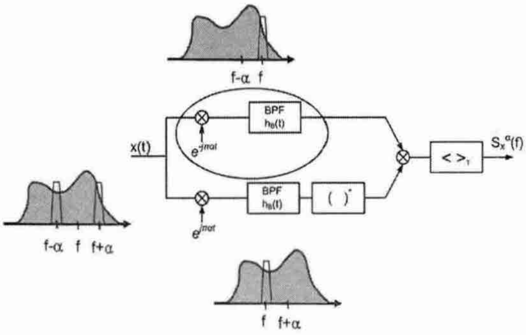
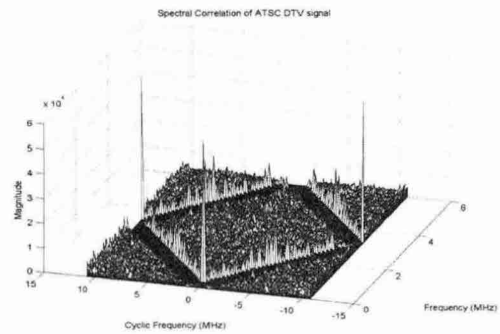
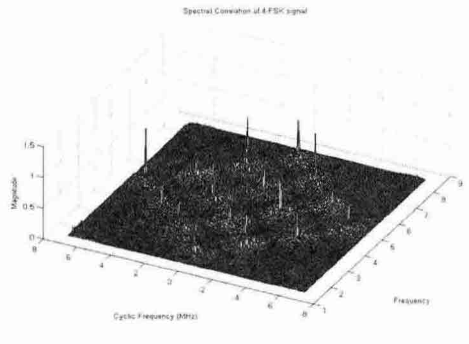


Fig 1. Block diagram to generate spectral correlation function



(a)



(b)

Fig 2. Spectral correlation of primary users signals. (a) AM signal (b) 4-FSK signal

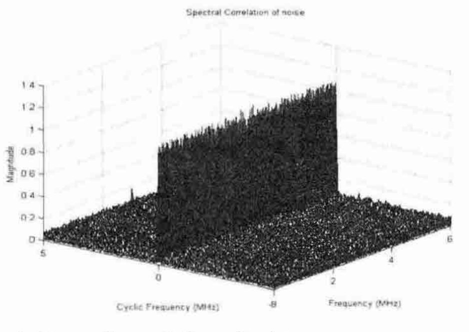


Fig 3. Spectral correlation of noise.

frequency. Another motivation of implementing spectral correlation for signal detection lies on its robustness to random noise and interference.

Spectral correlation of noise is significant large when cycle frequency equals to zero comparing to that of other values. Figure 3 shows the spectral correlation of noise, and the noise wall effect could be seen clearly at the zero cyclic frequency.

Ⅲ. Proposed Spectrum Sensing

1. Conventional Energy Detection Method

Energy detection is one of the conventional methods for signal detection which is one of the conventional methods for signal detection can be used for spectrum sensing. The classical energy detection which is also referred to as radiometry was first proposed by Urkowitz in 1967[11]. The detection procedure described is shown in figure 4. The energy detector consists of a noise pre-filter, a square law device and an integrator.

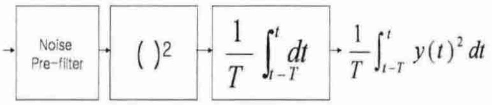


Fig 4. Block diagram of energy detection method

The noise pre-filter is used to keep the detected signal in the frequency band we desired. During the detection interval, the energy of the received signal is measured by the energy detector which will be used to deicide whether this frequency band is empty.

2. Proposed SCF Based Method

In energy detection method, the signal of interest is modeled as a stationary random process. However, in our proposed method, the signal of interest is modeled as a cyclostationary random process instead. Cyclostationarity of signal shows us another way for signal detection. In this paper, we propose an SCF based detection method under the innovation of cyclostationary theory. For spectrum sensing, some assumptions are explained. The proposed detection is used to detect the primary signal. We propose to utilize the spectral correlation properties for signal detection. The possible cycle frequencies of the received signal are stored in the receiver. When spectrum sensing begins, the detector checks all the possibile cycle frequencies one cycle by another. A certain criterion is set to decide whether the cycle frequency belongs to the received signal. After searching all possible cycle frequencies, a list of unique frequencies is compared the theoretical values of different modulated signal to decide the modulation type of the received signal. In the decision stage, we propose two criteria in a single cycle frequency. First criterion is based on energy measurement in a individual cycle frequency, and in a statistic based method.

1). Energy measurement based criterion

After calculating SCF of the received signal in a individual cycle frequency α_i, the energy in the frequency interval F is measured. This process is expressed in the following equation:

$$W(\alpha_i) = \sum_{i=1}^{F} (S_r^{\alpha_i}(f))^2 \qquad (8)$$

As the noise and interference level changes, the measured energy is a variable. Therefore, two normalized factor are used to make a spectral coherent function as shown in the following equation [8]:

$$C_r^{\alpha_i}(f) = \frac{S_r^{\alpha_i}(f)}{\sqrt{S_r(f+\alpha/2)S_r(f-\alpha/2)}} \qquad (9)$$

The square of this spectral coherence function is shown in (10). This function relates our propoesd energy measurement criterion to the spectral coherent function generally defined as the magnitude squared coherence function

$$C_r^{\alpha_i^2}(f) = \frac{S_r^{\alpha_i^2}(f)}{S_r(f+\alpha/2)S_r(f-\alpha/2)} \qquad (10)$$

We propose to utilize the spectral correlation

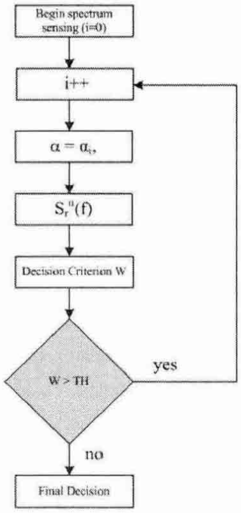


Fig 6. Detection Procedure of Proposed Method

properties for signal detection. The block diagram as shown in figure 6 explains the proposed detection method. Under hypotheses H_0, the received signal are only noise, the two terms in denominator can be treated as two independent Gaussian random process, and the probability distribution for $C_r^{\alpha}(f)$ is derived in[12]:

$$\Pr\{C < TH\} = 1 - (1 - TH)^{N-1} \quad \text{for } 0 \leq TH \leq 1,\ N \geq 2 \tag{11}$$

Therefore, the corresponding false alarm probability for the proposed detection method is:

$$\Pr\{C < TH|H_0\} = 1 - (1 - TH)^{N-1} \quad \text{for } 0 \leq TH \leq 1,\ N \geq 2 \tag{12}$$

Now, we can set our threshold for a desired false alarm probability independent of the input signal.

Ⅳ. Simulation Results

Computer simulations are made under AWGN. The ROC(Receiver Operating Characteristic) curves for both energy and proposed method are drawn to verify the performance. As shown in figure 7, the performance of the conventional energy detection is good in the high SNR level. However, as the SNR reduces, the performance

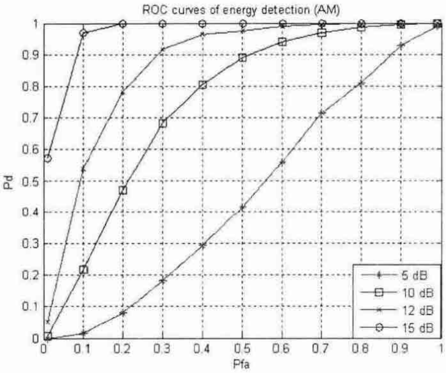


Fig 7. Energy detection of Conventional Method

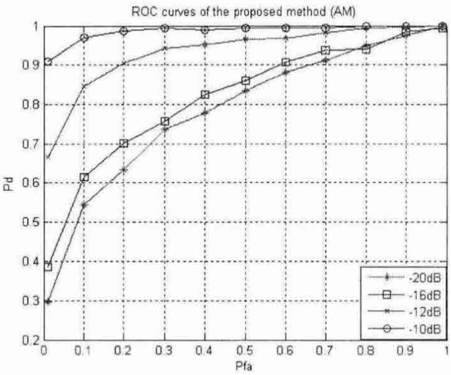


Fig 8. Energy detection of Proposed Method (in AWGN channel)

degradation is obviously to seen. We can easily find out the difference between the conventional method and proposed method. Detection probability is better using the proposed method even in the severe situation.

Simulations are also made under the satellite channel which is defined by ITU. Satellite cell wideband propagation models for the 2GHz band are proposed to represent the different environments: rural, suburban and urban which are based on extensive measurement campaigns. These models are typical in the elevation angles ranging from 15° to 55°. In addition to the narrowband description echoes due to multipath signals (near echoes) have to be taken into account according to the following equation.

$$w(t) = \sqrt{P_0}z(t) + \sqrt{P_1}g_1(t)z(t) + \sum_{i=2}^{M}\sqrt{P_i}g_i(t)z(t-\tau_i) \quad (13)$$

This model corresponds to a tapped-delay line

Table 1. Channel A parameter

Tap #	Relative tap delay value (ns)	Tap amp. distribution	Avg. amp. with respect to free space propagation	Rice Factor (dB)
1	0	LOS : Rice NLOS : Rayleigh	0.0 -7.3	10 -
2	100	Rayleigh	-23.6	-
3	180	Rayleigh	-28.1	-

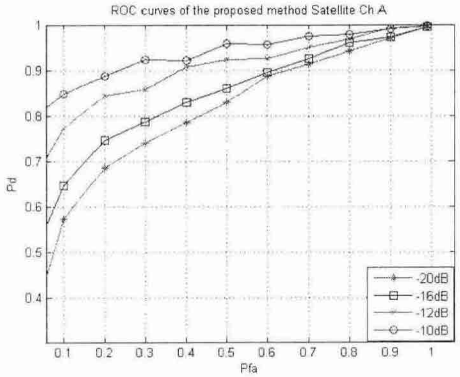


Fig 9. Energy detection of Proposed Method (in Satellite A channel)

structure with a fixed number M of taps with a direct path and M-1 echoes with tap delays τ_i and randomly time varying tap amplitudes.

From the figure 9, we can get another ROC curves which is simulated in satellite channel A, as shown in table 1. As shown, the proposed detection method shows better detection probability even in the low SNR. We can find that the higher SNR, the better detection probability.

V. Conclusion

In this paper, spectral correlation based detection method is proposed for spectrum sensing in cognitive radio. Spectrum sensing in satellite bands are carried out based on the proposed method. We proposed detection criteria for the detection method. It is analysed. The conventional energy detection method is studied as a comparison. Simulation results show that the proposed method outperforms the conventional energy detection method even in low SNR and it is believed to be more suitable for spectrum sensing in cognitive radio.

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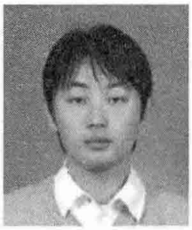

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